MINIATURE LOW POWER SUBMILLIMETER-WAVE SPECTROMETER FOR DETECTION OF WATER IN THE SOLAR SYSTEM

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ABSTRACT

Mass and power for the next generation of NASA's heterodyne spectrometers must be greatly reduced to satisfy the constraints of future small-spacecraft missions. We report on a 220 GH7. Schottky-diode receiver, which requires less than 4.8 W, and has a mass of less than 1.5 kg - more than a factor of ten reduction in mass and power compared to current instruments. This significant savings was achieved through minimizing the number of receiver components, without compromising on the functionality necessary for a surface based Mars atmospheric sounding instrument.

INTRODUCTION

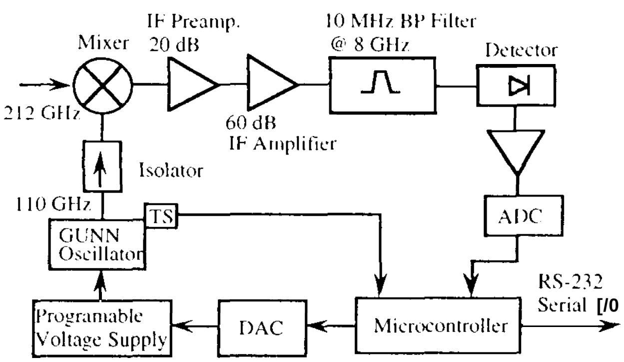
The transformation of water from ice to vapor is one of the most powerful forces for change on planets and small planetary bodies. [1-2]. One of the strongest transitions of the H_2O molecule, the ground state transition, occurs near 557 GHz, in the submillimeter wavelength region. A capable spectrometer operating in the vicinity of this spectral line can be used to address many of the needs of future Solar System exploration missions. For example, on Mars, such an instrument can characterize the nature and the dynamics of the planetary boundary layer by determining pressure, temperature, and humidity over diurnal and seasonal cycles, with measurements of thermal spectral line emissions from CO (near 577 GHz) and H_2O.

The mass and power typical of current heterodyne spectrometers must be greatly reduced to make them viable as candidates for future small spacecraft missions. For instance, the Microwave Limb Sounder currently flying on the Upper Atmospheric Research Satellite, (with three heterodyne radiometers at about 63 GHz, 185 GHz and 203 GHz), has a mass of 283 kg and requires 162 W of DC power [3]. The Submillimeter Wave Astronomical Satellite (with two heterodyne receivers, at about 490 GHz and 555 GHz), to be launched in 1997, has a total mass of 92.5 kg, and requires 60.7 W [4]. The Microwave instrument for the Rosetta Orbiter (with two heterodyne receivers at 236 GHz and 562 GHz, and a full back-end spectrometer) is anticipated to have a mass of 16.2 kg, and require 61 W [5]. Such instruments arc highly capable, but too large to be implemented in small-spacecraft missions such as those for the Mars Surveyor Program [6].

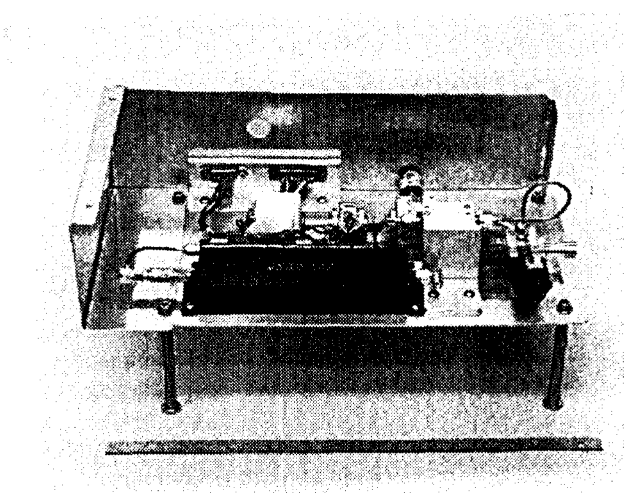
Here we report on a prototype instrument for the detection of water throughout the Solar System, with a total mass of less than 1.5 kg (exclusive of telescope) and a DC power requirement of less than 4.8 W. This great reduction in mass and power was achieved through minimizing the number of receiver components, while still maintaining adequate functionality for a surface based Mars atmospheric sounding instrument. Frequency scanning is achieved by tuning the local oscillator (LO), thus eliminating the need for filter banks or back-end spectrometers. In this case, frequency multiplexing capability has been traded for low mass and power, which increases the time required to obtain a spectrum of the atmospheric emission, a condition which is entirely, acceptable for Mars sounding applications. The downconverted signal from the mixer is detected at the first intermediate frequency (IF) so that no further downconversion is necessary, which eliminates the need for additional low frequency LO sources and amplifiers. A novel frequency control technique is also implemented here, which uses bias-tuning of the GUNN oscillator to produce the desired LO frequency over a wide range of temperature, thus eliminating the need for phase-locked loop and active thermal control systems.

EXPERIMENTAL RESULTS

With the 557 GHz mixer and associated multiplier chain still under development, we prototyped a 220 GHz version of the instrument



(a)



(b)

Fig. 1 (a) A block diagram of the 220 GHz radiometer, and (b) a picture of the prototype. The 220 GHz prototype has a mass of 1.05 kg, a power requirement of 4.8 W, and dimensions of 30 x 15 x 10 cm.

to verify the receiver concept. A block diagram of the 220 GHz radiometer is shown in Fig. 1a, and a picture of the prototype appears in Fig. 1 b. The heterodyne receiver uses a subharmonic planar Schottky-diode mixer [7], an InP temperature compensated GUNN oscillator at 110 GHz (tunable over 0.5 GHz) for the LO, and an IF at S GHz with a 10 MHz bandpass filter. Measured mass and power for this receiver arc shown in 'l'able 1. Off-the-shelf amplifiers were used in this prototype. The total power is about evenly divided between the IF amplifier chain and the GUNN oscillator. Though the 10 MHz filter takes considerable space (black box in Fig. lb), its mass is relatively small (220 g) and it does not require any power.

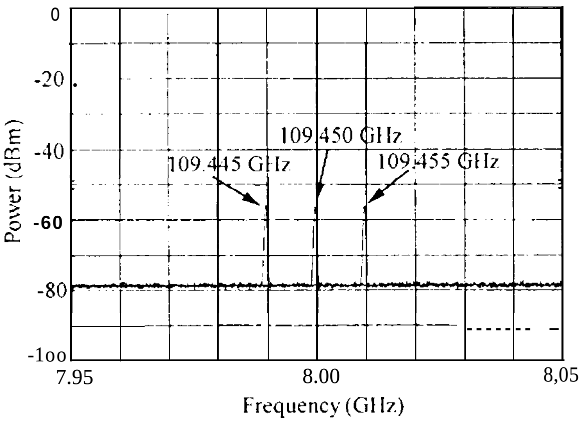
	MEASURED 220 GHz		PROJECTED 560 GHz	
Component	M [g]	P [mW]	M [g]	P [mW]
feedhorn	50			
mixer	280		100	
IF amp	50	2500	10	1000
filter	220		400	
detector	20		40	
ADC	40	100	80	200
micro-processor	60	100	60	100
DAC	50	100	50	100
GUNN	-to	moo	40	2000
submmw multiplier			100	
mmw isolator	-10		40	
wiring			100	
structure	200		300	
total	1050	4800	1320	3400

I'able I. Total mass and power measured for the 220 GHz prototype, and projected for a planned 560 GHz receiver. MMIC amplifiers are expected to reduce the required power by about 1.5 W.

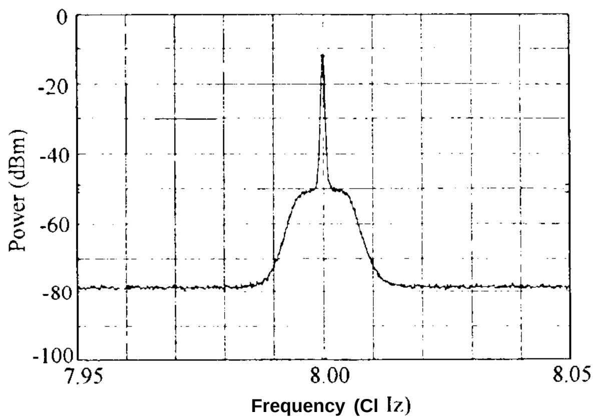
Projected mass and power for a 560 GHz receiver, with MMIC amplifiers, are also shown in Table 1. In this submillimeter wave version, the 280 GHz LO would be produced by a 140 GHz GUNN oscillator driving a multiplier. Two detection channels would then be required, since currently available 140 GHz GUNN oscillators cannot be bias tuned over a wide enough frequency range to detect both the H_2O and CO lines simultaneously. The submillimeter wave multiplier and second detection channel would increase the total mass by about 300 g over the millimeter wave prototype, while MMIC amplifiers are expected to reduce the required power by about 1.5 W.

Low power LO frequency control is accomplished through a feedback loop, which consists of a temperature sensor mounted on the GUNN oscillator, a microcontroller, and a programmable voltage supply. The GUNN bias voltage is adjusted by the microcontroller, to compensate for any frequency drift caused by changes in temperature, thus eliminating the need for phase-locked loop and active thermal control systems. An accuracy of approximately 2 MHz was achieved for the LO (4 MHz for the IF), which is sufficient for detection with a 10 MHz-wide IF filter. To further insure the accuracy of the LO frequency, measurements symmetrically offset from the center of a spectral line will be compared. The full content of a spectral line will be observed by varying the GUNN oscillator bias to sweep the LO frequency, while detecting the IF signal at 8 GHz. The availability of low loss filters limits the IF frequency resolution to about 1: 10^3. For applications requiring higher resolution than 10 MHz this approach is still feasible, but requires filter development.

The prototype receiver was tested using a laboratory signal source, a PC as a controller, and a spectrum analyzer as a detector. The signal source consisted of a frequency synthesizer (HP 83623A), a source module (HP 83557A, X4 multiplier), and a frequency tripler [8]. To demonstrate LO tunability, a fixed signal was observed at 210.9 GHz with three different LO settings (109.445 GHz, 109.450 GHz and 109.455 GHz) and monitored at the output of the mixer, as shown in Fig. 2a. Since the laboratory source produced a very narrow signal, less than 1 MHz wide (Fig. 2a), it was not possible to observe different parts of the spectral line by sweeping the LO. The functionality of the end-to-end receiver was therefore demonstrated by varying the signal frequency, and adjusting the LO frequency accordingly to always produce an IF signal at 8 GHz. The output of the IF filter for a signal at 210.9 GHz and an LO frequency of 109.450 GHz, is shown in Fig. 2b.



(a)



(b)

Fig. 2 (a) The output of the mixer for a fixed signal at 210.9 GHz, with LO settings of 109.445 GHz, 109.450 GHz, and 109.455 GHz, demonstrating LO tunability, and (b) the output of the IF filter for a signal at 210.9 GHz, with 1.0 set at 109.450 GHz.

CONCLUSIONS

We have demonstrated the reduction in mass and power for a functional heterodyne receiver system by more than a factor of 10 over existing systems, thus creating a powerful tool for future space missions .- A 220 GHz radiometer with a total mass of less than 1.5 kg, which uses less than 4.8 W of DC power, was designed, assembled, and tested. Further power reduction in excess of 1 W will be achieved by using MMIC amplifiers.

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REFERENCES

[1] C. B. Farmer, D. W. Davis, A. L. Holland, D. D. LaPorte, and P. E. Doms, "Mars water vapor observations from the Viking Orbiters, " *J. Geophys.* ***Res.,*** vol. 82, no. 28, pp. 4225-4248, 1977.

[2] F. L. Whipple, " A Comet Model. I. The Acceleration of Cornet Encke,"*Astrophys. J.*, vol. 111, pp. 375-394, 1950.

[3] F. T. Barath et all, "The Upper Atmosphere Research Satellite Microwave Limb Sounder Instrument, " *J. Geophys. Res., vol.* ***98,*** no. D6, pp. 10751-10762, June 20, 1993.

[4] Private communication, G. Chin.

[5] Private communication, M. A. Frerking.

[6] S. L. Miller, R. T. Gamber, and L. E. Lowry, "Mars Surveyor Missions: 2001 and Beyond, " *Second IAA International Conference on Low-Cost Planetary Missions,* Session IV- Lunar and Inner Planets Missions, Ref. No. IAA-L-0404, 1996.

[7] I. Mehdi, M. Mazed, R. Dengler, A. Pease, M. Natzic and P. H. Siegel, "Planar GaAs Schottky Diodes Integrated with Quartz Substrate Circuitry for Waveguide Subharmonic Mixers at 215 GHz," 1994 *IEEE MTT International Microwave Symposium Digest*, pp. 779-782.

[8] A. V. Raisanen, D. Choudhury, R. J. Dengler, J. E. Oswald, and P. H. Siegel, "A Novel Split-Waveguide Mount Design for Millimeter- and Submillimeter-Wave Frequency Multipliers and Harmonic Mixers," *IEEE Microwave and Guided Wave Letters,* vol. 3, No. 10, pp. 369-371, October 1993.